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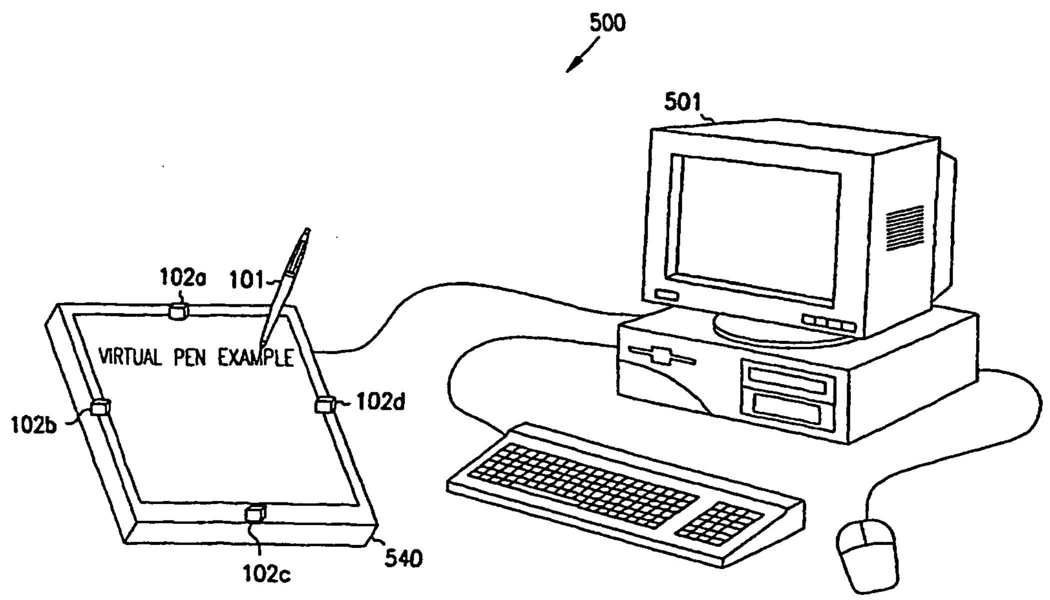

(57) Abstract

A virtual pen computer input device includes a stylus (101) which transmits coded ultrasonic sound waves, and a receiver circuit using a plurality of microphones (102a–d) to receive the coded ultrasound. The ultrasound is at a frequency which is too high for human detection. The signals received by the plurality of receiving microphones are compared by a processor executing location algorithms to determine the position of the stylus. Direct sequence pseudo random codes in the ultrasound signals are unique to each virtual pen systems such that interference between adjacent virtual pen users is virtually eliminated.

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PEN INPUT DEVICE FOR A COMPUTER

The present is application is based upon U.S. Provisional Patent Application Serial Number 60/130,848, entitled "Virtual Pen" filed April 22, 1999. The present application claims the benefit of the earlier priority date under 35 U.S.C. § 119(e).

Copyright Notice/Permission

Field of the Invention

The present invention relates to information systems and in particular, the present invention relates to information input devices for digital computer systems.

Background of the Invention

The pencil or pen is the oldest known writing device and one which people are most comfortable using when recording information. Thus, the pencil or pen has been adapted for use for several types of input devices for digital computer systems since it seems like a natural extension to what people are used to using. Computer devices such as palm computers are based entirely upon the use of a facsimile of a pen as the sole input device. Even traditional pen manufacturers such as Cross are adapting pens for use in the computer world. The problem in adapting a pen or pen facsimile for use as an input device is determining the location of the pen and its vector (direction, velocity, etc.). It is

desirable to have a pen-type input device which can serve to replace a computer mouse, and perform additional functions in a cost effective manner.

U. S. Patent No. 3,838,212 entitled "Graphical Data Device" to Whetstone et al., describes a graphical data device employing a stylus moving over an area to be digitized and utilizing a fast rise time sound energy shock wave, generated by a spark at the location of the stylus and propagated through the air for providing coordinate information as to the instantaneous position of the spark. Receiver devices are positioned along X and Y coordinates and respond to the leading edge of the air propagated shock wave front to provide an elapsed time indication from the moment of spark generation to the moment of shock wave reception. A three dimensional configuration is also described utilizing a three coordinate receiver. The Whetstone device uses a stylus that is physically connected to a writing pad. Two microphones are placed on the plate. Three microphones are used for the three-dimensional positioning. The pulses that are transmitted through the air are short sparks and the location is measured directly by converting the propagation time in the atmosphere to Cartesian co-ordinates. The transmission is done once a pressure switch senses the pressure touch on the plate. This early device is crude in design and cannot serve to replace a computer mouse as an input device.

U. S. Patent No. 4,246,439 entitled "Acoustic Writing Combination, Comprising A Stylus with An Associated Writing Tablet" to Romein, describes an acoustic writing combination which includes a stylus with an associated writing tablet. The stylus is provided with two ultrasonic sound sources which, upon contact of the stylus with the writing tablet, emit pulse-shaped sound signals which are picked up by at least two microphones which are located at the edge of the writing tablet. The two sound sources are situated at different distances from the stylus tip and are operated to alternately produce ultrasonic signals. Point-shaped or circular sound sources may be employed. The circular sound sources may comprise piezoelectric ceramic rings. This device is similar to the Whetstone et al., device described above except this patent provides further details regarding the implementation and solves one of the major drawbacks of the previous implementation: in practice, it is impossible to insert a speaker in the tip of the stylus. The Romein patent suggests that two

speakers will be positioned in the stylus and will be transmitting acoustic pulse trains alternatively. By a simple interpolation, and by knowing the distance between the speakers, the real position of the tip could be estimated. However, it is not clear whether the Romein stylus is physically connected to the pad and the issues of calibration are not addressed.

U. S. Patent No. 4,814,552 entitled "Ultrasound Position Input Device" to Stefic et al., describes an input device, or stylus, for entering hand drawn forms into a computer comprising a writing instrument, a pressure switch for determining whether the instrument is in contact with the writing surface, an acoustic transmitter for triangulating the position of the stylus on the surface, and a wireless transmitter for transmitting data and timing information to the computer. In operation, the stylus transmits an infrared signal which the system receives immediately, and an ultra sound pulse which two microphones receive after a delay which is a function of the speed of sound and the distance of the stylus from each microphone. From this information the system can calculate the position of the stylus. Switches for indicating functions are mounted on the stylus. Multiple styli can be used, each transmitting a distinctive identification code so that the system can determine which stylus is the signal source. The Stefic et al. device has several innovations compared to the previously described patents. The stylus contains an infrared transmitter, which eliminates the need for the stylus to be physically connected to the writing pad. The infrared pulse is the reference and the distance is estimated by the time of arrival of the ultrasonic pulse after the infrared pulse. The stylus contains several pushbutton switches which allow the user to change functionality of the device such as changing the pen color, toggling between solid and dashed line, line width, etc. The purpose of the Stefic et al. patent is to allow adding hand written data into the computer. The infrared and the ultrasonic pulses are generated upon the stylus touching the writing pad. This device cannot function as a mouse replacement, however, and calibration issues are not discussed.

U. S. Patent No. 5,308,936 entitled "Ultrasonic Pen-Type Data Input Device" to Biggs et al., describes a wireless pen as a computer input device which moves over the surface of a tablet. The pen will simultaneously emit magnetic pulses and ultrasonic pulses. The tablet id equipped with a magnetic

detection coil and two microphones. The magnetic detection coil nearly instantaneously detects the magnetic pulse and serves as a time reference for determining the time it takes to detect the ultrasonic pulses. The detection circuitry detects a specific point within the ultrasonic pulse and the time travel of the sonic pulse to the two microphones is used to determine the distance of the pen from the two microphones yielding the position of the pen over the surface of the tablet. The pen is not attached to the pad but rather sends magnetic pulses as a reference. The pulses are generated upon the touch of a switch (in the tip of the pen) with the writing pad. The Biggs et al., patent also describes a noise riding threshold for timing estimation, temperature calibration, position calibration using eight known points on the pad is described, and the smoothing the data with ARMA (auto regressive moving average) filtering. This device cannot operate as a mouse replacement.

U. S. Patent 5,657,054 entitled "Determination of Pen Location on Display Apparatus using Piezoelectric Point Elements: to Files et al., describes a stylus location system utilizing a field emission device having an anode plate and an emitter plate and a plurality of piezoelectric point elements coupled to the anode plate. The piezoelectric point elements are capable of transforming electrical energy into ultrasonic energy and transforming ultrasonic energy into electrical energy. A stylus is also coupled to the anode plate and circuitry is coupled to the piezoelectric point elements for determining the position of the stylus. The circuitry may also send a video data signal to the emitter plate in response to the position determination. The Files et al., device has two important features not found in the above described devices. First, the pen does not have to touch the surface since the surface is covered with piezoelectric elements and the coupling between the pen and the surface does not need to be by contact. Second, the Files et al., invention is designed as a mouse replacement by allowing pointing on the screen directly. The piezoelectric plate could be placed in front or behind the displaying area. However, the Files et al., device does not use the propagation time in the atmosphere as the means for determining the position.

An electronic pen and CrossPad™ writing tablet from A. T. Cross Company allows for drawing figures and writing text on a tablet, converting the text to electronic form and downloading the converted text and graphics to a

computer. The electronic pen sends RF signals to the electronic notepad when the pen touches the notepad. See www.cross.com.

As one skilled in the art will recognize, and in light of the shortcomings of the prior art described above, there is a need in the art for an improved virtual pen computer input device which can serve as a replacement for a mouse at approximately the same cost as a mouse, which does not touch the computer display device, and which can be added to existing computer systems.

Summary of the Invention

The present invention solves the above deficiencies in the art as well as solving other advantages which will be understood by those skilled in the art upon reading and understanding the following description. The present invention describes a virtual pen which includes a stylus which transmits coded ultrasonic sound waves, and a receiver circuit using a plurality of microphones to receive the coded ultrasound. The ultrasound is at a frequency which is too high for human or biological detection. The signals received by the plurality of receiving microphones are compared by a processor executing location algorithms to determine the position of the stylus based upon the different time of arrival of the signals at the microphones. Direct sequence (pseudo random) codes in the ultrasound signals are unique to each virtual pen systems such that interference between adjacent virtual pen users is eliminated. A low duty cycle of the ultrasonic waves also aids in minimizing interference between adjacent users.

Brief Descriptions of the Drawings

In the drawings, in which like reference numbers represent like components throughout the several views, where the leftmost digits of the reference numbers correspond to the Figure first describing the component, and where the rightmost digits of the reference numbers generally describe similar components throughout the several views.

Figure 1 is a perspective view of the present invention of a virtual pen attached to a computer screen.

Figure 2 is a block diagram of the electrical components and operational features of the stylus of the present invention.

Figure 3 is an electrical schematic block diagram of the receiver circuit of the present invention.

Figure 4 is a perspective view of the present invention implemented as an input device for a portable computer.

Figure 5 is a perspective view of the present invention implemented as an input device for a desktop computer.

Detailed Description of the Preferred Embodiments

In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific embodiments in which the inventions may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that process or mechanical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims. The mathematical variables used throughout this description of the invention use descriptors which are consistent with commonly used textbook descriptors for mathematical modeling and electromagnet theory. Since these variables and their descriptors are known to those skilled in the art, some variables in this patent application are only briefly defined.

Overview of the Invention

The present invention describes a virtual pen for use as a computer input device which allows pointing precisely at any selected point on a computer screen as well as being a low cost replacement for a touch pad or drawing tablet. The virtual pen of the present invention uses ultrasonic technology in conjunction with modern radar and communication technology (direct sequence pseudo random codes). Conjoining these technologies enables the production of a low cost and versatile device, which outperforms the existing competing devices. The technology of the virtual pen of the present invention has many embodiments and applications such as direct input of handwriting into the computer, input through a touch-pad, and automatic measurement of distances on paper maps, diagrams or direct measurement and recording of three dimensional physical objects. In one embodiment, the virtual pen of present invention also serves as a low cost computer mouse replacement. Although the virtual pen of the present invention is

designed mainly for laptop or palmtop computers, which currently use joysticks or touchpads as input devices, the applications of the present invention are many, as illustrated below. For example, and not by way of limitation, an alternate embodiment the virtual pen of present invention may be implemented as a relatively low cost drawing tablet for computer input. Currently, computer drawing tablet devices are expensive, especially when they have large active drawing area.

As described more fully below, the use of the virtual pen of the present invention is easy since the stylus is a pen-like device familiar to everyone. The user simply points the stylus near the computer screen to position the cursor without actually touching the screen. In one embodiment, selection options under control by the user include approaching the stylus closer to the screen to select an object or text. The present invention optionally includes the equivalent of "right" and "left" mouse pushbuttons mounted on the stylus.

In alternate embodiments, the virtual pen of the present invention could be used as a replacement for a computer touchpad or as a simple joystick as well as a tool for drawing graphical shapes in commercial presentation graphics program such as Microsoft® PowerPoint® or Visio®. The virtual pen of present invention is manufactured at a cost which is comparable to a computer mouse. In use, the stylus of the virtual pen of present invention does not touch the computer screen. This is an important distinction over existing technologies since damage to the screen is minimized, especially with modern CCD computer displays, plasma displays, cold-cathode field emission displays, and other flat screen technologies in which strengthening the screens to endure excessive depressing or contact is unnecessary. As described more fully below in conjunction with one of the preferred embodiments of the present invention, the present virtual pen is designed to be an economical and efficient add-on to existing computers.

Referring to Figure 1, the present invention 100 uses ultrasonic sound waves to provide the spatial location of the stylus 101 and the speed of the motion of the stylus. The ultrasound is at frequencies undetectable by the biological ear. The tip of the stylus 101 of the present invention contains an ultrasonic transducer or speaker that generates special waveforms, described below, which are detected by a plurality of ultrasonic receivers or microphones

102a, 102b, 102c, 102d located around the periphery of the computer screen 103. The position of the stylus 101 is determined by measuring the difference in time that it takes the ultrasonic wave to reach the microphones, generally 102. In one embodiment of the present invention, four microphones 102a, 102b, 102c, 102d are used. The stylus 101 contains a motion sensor, a touch sensor, a processor, an ultrasonic speaker and batteries. The touch sensor may be implemented by measuring the impedance between conductive strips 208a and 208b, or by measure pressure due to the grip of a user's hand, or by some other sensing mechanism. The motion sensor detects when the stylus is in motion.

In one embodiment, the stylus 101 generates a burst of ultrasonic pulses for 10.24 milliseconds every 0.2 seconds. In a preferred embodiment of the present intention, the waveform of the ultrasonic pulses is a direct sequence pseudo random code at a rate of 100 kHz, on a carrier frequency of 200 kHz. The sequence is 127 chips long constituting a single bit, and 8 bits are transmitted for each pulse. The stylus 101 will begin transmitting the ultrasonic pulses as a result of two conditions: a motion sensor is triggered by movement of the stylus 101 and the user holding the stylus has activated the touch sensor. The plurality of microphones pick up the transmitted signals designated r_1, r_2, r_3 and r_4. The ultrasonic signals arrive at the microphones 102 at a slight difference in time according to the spatial position of the stylus 101 relative to the microphones 102. The position is determined by computing the most probable point and a further dynamic calculation is made in order to account for past position of the stylus. The speed of the sound wave is dependent on local air pressure and humidity, therefor, a calibration speaker 104 on the plate calibrates the speed of the ultrasonic wave by transmitting a calibration pulse every few minutes.

The direct sequence pseudo random code is used for differentiating various styli from each other and for eliminating the effect of multipath distortion. The direct sequence code is transmitted 8 times, allowing for 7 information bits modulated as deferential binary phase shift keying (DBPSK) in which a ONE will be determined by the reversal of the sequence compared to the previous bit sequence. The 7 bits of information are interpreted as 127 various messages that are used for indications such as pushbutton depression, low battery, etc. In one embodiment, the stylus batteries are simple button-shaped Lithium batteries or

rechargeable Lithium batteries. The low speaker power and the 5% duty cycle consume minimal energy from the stylus 101. A stylus cradle is used as a charger station and for selecting and synchronizing the direct sequence code when the stylus is in its cradle.

Implementation of the Present Invention

Figure 2 is a block diagram of the operational features of the virtual pen of the present invention for one embodiment. A microprocessor 206 is used to control the operation of the stylus 101. In one embodiment of the present invention illustrated in Figure 2, two speakers 207a, 207b of stylus 101 send a sequence of ultrasound pulses indicating its position to the receiving plate. Those skilled in the art will readily recognize that one speaker or transducer may suffice, or that a great number of speakers may be preferred. Again, in one embodiment, the stylus 101 generates a sequence of pulses approximately every 0.2 seconds or 200 milliseconds. The burst lasts approximately 10 milliseconds such that a 5% duty cycle is achieved. Those skilled in the art will readily recognize that a variety of duty cycles, burst lengths, burst cycle times and frequency of the carrier may be varied without departing from the scope of the present invention.

Each ultrasonic pulse is coded with a sequence of 8 maximal length sequences 127 bits long over a audio carrier having a carrier frequency of 200,000 kHz. The stylus generates the pulses only when some resistance is sensed between the conducting strips 208a, 208b from a user's hand, and an indication from the motion sensor 209. The ultrasonic sequences are coded to be unique to each virtual pen so that adjacent users will not suffer interference with their respective virtual pens. When the stylus 101 is mounted in its cradle (not shown), the batteries 210 are charged and the microprocessor 206 synchronizes the transmission code sequence and the timing of the pulses.

Referring to Figure 3, an electrical schematic block diagram of the receiving circuit 300 for the virtual pen system of the present invention is shown. A plurality of microphones 102, which in one embodiment, four are used 102a, 102b, 102c, 102d, drive amplifiers 324a, 324b, 324c, 324d, respectively, with the received ultrasound signals being converted to digital signals by analog-to-digital converter 323. The digitized ultrasound signals are processed by microprocessor 306 to demodulate the signals, filter out signals which are coded for a different

stylus (such as received from another virtual pen used located nearby), and decode any commands transmitted by the stylus 101 (such as a low battery signal). The microprocessor 306 uses location algorithms described below to determine the X-Y (two-dimensional implementation) or X-Y-Z (three-dimensional implementation) Cartesian coordinates of the stylus tip. The microprocessor then converts the stylus position into millimeters or whichever location parameters are required by the host computer, and sends the coordinates though the computer mouse interface 328 to the host computer (not shown in Figure 3). The speed at which the stylus moves can also be calculated. Thus, since the stylus coordinates received by the host computer are identical to mouse position coordinates, the virtual pen system of the present invention is a plug-compatible replacement for a computer mouse.

The microprocessor 306 of the receiver 300 also generates pulses 320 for calibration through a calibration speaker 104. The calibration pulses are generated about every 5 minutes and are also approximately 10 millisecond in length, which is too short for a biological ear to sense such that the users will not notice the sounds. Special codes unique to each virtual pen system identifies the calibration pulses. The calibration pulses allow the virtual pen system to identify the speed of the ultrasonic wave, which will vary according to air temperature and pressure. The calibration process is used for self test and is continuously monitored for changes by microprocessor 306. The microprocessor 306 compares the time and phase of the received pulses to the transmitted pulses to monitor changing conditions. Thus, when the microprocessor converts the stylus location coordinates into ranges in millimeters, it also corrects for location temperature and pressure variations to compensate for the varying speed of the ultrasonic wave computed during the calibration process.

The measurement of the stylus location is further enhanced by the microprocessor which maintains a history of previous measurements in memory 322 and by using a Kalman filter to computes the first and second derivatives of the motion of the stylus. The results of this computation is also used for enhancement of the accuracy of determining the spatial position and avoid erroneous locations.

The receiver circuit 300 selects the transmitting sequence and the timing of the stylus 101 when it is located in the cradle 321. The cradle serves to charge the stylus batteries and to synchronize the receiver circuit 300 with the stylus 101.

Operational Algorithms of the Present Invention

As described above, one embodiment of the present invention utilizes four receiving microphones 102a, 102b, 102c, 102d, although those skilled in the art will readily recognize that a greater or lesser number of microphones are possible without departing from the scope of the present invention. Thus, the algorithms described here are based on four receiving microphones but the algorithms can be converted to operate with a greater or lesser number of microphones.

To convert the stylus measurements Cartesian coordinates is accomplished by applying trigonometric formulas for measurements of four ranges. This conversion utilizes the cosine theorem in a triangle). To begin, label the position of the virtual pen in a three dimensional space as having a location x = [x, y, z]. Let T_0 define the time in which the pulse left the stylus. The plane of the computer screen (or tablet) is at z = 0. The four microphones 102a, 102b, 102c, 102d are defined as being located at positions $[x_i, y_i, 0]$, where I = 1,2,3,4. The pulses are measured at times T_i, where I = 1,2,3,4, to correspond to the four microphones, and V is the speed (velocity) of the ultrasonic wave. The formal solution for a single measurement is as follows

$$
\begin{aligned}
(x - x_1)^2 + (y^2 - y_1)^2 + z^2 &= V^2 * (T_1 - T_0)^2 \\
(x - x_2)^2 + (y^2 - y_2)^2 + z^2 &= V^2 * (T_2 - T_0)^2 \\
(x - x_3)^2 + (y^2 - y_3)^2 + z^2 &= V^2 * (T_3 - T_0)^2 \\
(x - x_4)^2 + (y^2 - y_4)^2 + z^2 &= V^2 * (T_4 - T_0)^2
\end{aligned}
$$

Subtracting the equations:

$$x_1^2 - x_2^2 - 2x(x_1 - x_2) + y_1^2 - y_2^2 - 2y(y_1 - y_2) = V^2\left(T_1^2 - T_2^2\right) - 2V^2T_0\left(T_1 - T_2\right)$$
$$x_2^2 - x_3^2 - 2x(x_2 - x_3) + y_2^2 - y_3^2 - 2y(y_2 - y_3) = V^2\left(T_2^2 - T_3^2\right) - 2V^2T_0\left(T_2 - T_3\right)$$
$$x_3^2 - x_4^2 - 2x(x_3 - x_4) + y_3^2 - y_4^2 - 2y(y_3 - y_4) = V^2\left(T_3^2 - T_4^2\right) - 2V^2T_0\left(T_3 - T_4\right)$$
$$x(x_1 - x_2) + y(y_1 - y_2) - T_0V^2\left(T_1 - T_2\right) = x_1^2 - x_2^2 + y_1^2 - y_2^2 - V^2\left(T_1^2 - T_2^2\right)$$
$$x(x_2 - x_3) + y(y_2 - y_3) - T_0V^2\left(T_2 - T_3\right) = x_2^2 - x_3^2 + y_2^2 - y_3^2 - V^2\left(T_2^2 - T_3^2\right)$$
$$x(x_3 - x_4) + y(y_3 - y_4) - T_0V^2\left(T_3 - T_4\right) = x_3^2 - x_4^2 + y_3^2 - y_4^2 - V^2\left(T_3^2 - T_4^2\right)$$

Assuming V=1 and putting the solution in matrix form:

$$\begin{pmatrix} x_1 - x_2 & y_1 - y_2 & -T_1 + T_2 \\ x_2 - x_3 & y_2 - y_3 & -T_2 + T_3 \\ x_3 - x_4 & y_3 - y_4 & -T_3 + T_4 \end{pmatrix} \begin{pmatrix} x \\ y \\ T_0 \end{pmatrix} = \begin{pmatrix} x_1^2 - x_2^2 + y_1^2 - y_2^2 - T_1^2 + T_2^2 \\ x_2^2 - x_3^2 + y_2^2 - y_3^2 - T_2^2 + T_3^2 \\ x_3^2 - x_4^2 + y_3^2 - y_4^2 - T_3^2 + T_4^2 \end{pmatrix}$$

There are several possible sources of error in determining the accurate position of the stylus tip. The size of the speaker 207 or speakers 207a, 207b and the microphones 102 must be sized correctly in order to achieve less than a millimeter spatial error. The speaker size should be in the order of the wavelength to be effective which is 1.7 mm. The speaker size imposes inherent error but the size does not create relative local errors: improperly sized speakers will create deformation on a large sheet of paper.

The ultrasound wave is expected to propagate as an omni-directional wave but it will propagate through the paper at higher speeds (although attenuated) and it will be reflected from the user's hand and other elements in the neighborhood of the virtual pen system. The effect of this sonic propagation error is similar to multipath effect in RF communication. This sonic propagation error is resolved by applying an adaptive filtering process for eliminating the reflections and isolating the main ultrasonic wave. Note that only the first incoming wave is of interest and the maximal length sequence will suppress the reflections.

Errors due to processing of the received ultrasonic wave, phase distortion or deformation and the finite size of the analog-to-digital converter (ADC) 323 create processing errors. The mathematically derived estimate is that the overall error will be around 30 of the wavelength, as follows:

$$E_d = V/f * E. = 340*10^3 / 2*10^5 * (30/360) = 0.142 \text{ mm}$$

Environmental noise may also contribute to the error in accurately determining the stylus tip location. High pass filters are used to remove any energy below 100 kHz to suppress environmental noise. High frequency ultrasonic waves rapidly decay while propagating in the air so the ultrasound will be contained in a very small area around the virtual pen system.

Cross interference or crosstalk may also contribute to location error. Using a multitude of virtual pen systems in a small physical area will create cross interference between the systems. The cross interference might confuse the microprocessor 306 causing it to misidentify the stylus corresponding to its virtual pen system. The chance of a misidentification is eliminated by using various sequences (unique direct sequence pseudo random patterns) and trailers having identification information within the code sequence. Also, a time tracking algorithm is used for filtering the pulses in time such that pulse outside the maximum time window for the size of the computer screen are eliminated.

During the writing process the z-axis is hardly changed, therefore, for error evaluation, a two-dimensional distribution is formulated using the covariance matrix:

$$p(\overline{x}) = \frac{|R|^{-1}}{2\pi} \exp\left(-\frac{1}{2}\overline{x}^T R^{-1} \overline{x}\right)$$

$$\overline{x} = (x, y)$$

$$R \equiv Co\operatorname{var}iance\_Matrix$$

$$R^{-1} = \begin{bmatrix} G_1 & G_3 \\ G_3 & G_2 \end{bmatrix}$$

Each range measurement contributes to the inverse covariance matrix by adding more information and consequently reducing the size of the uncertainty ellipse. The probability is expressed as:

$$P = \frac{1}{2\pi K} \oiint_{eq\_probability\_ellipse} \exp\left[-\frac{1}{2}\left\{ G_1 x^2 + G_2 y^2 + 2 G_3 xy \right\}\right] dxdy$$

Assuming that the microphones are at (0,-a), (0,0), (0,a) the ranges are:

$$R_1 = \sqrt{x^2 + (y+a)^2}$$
$$R_2 = \sqrt{x^2 + y^2}$$
$$R_3 = \sqrt{x^2 + (y-a)^2}$$

The error projection on the Cartesian co-ordinates is:

$$G_1 x^2 = \sum_{i=1,2,3} \frac{1}{\sigma_{x_i}^2} = \frac{1}{\sigma_R^2} \sum_{i=1,2,3} \left(\frac{\partial R_i}{\partial x} \right)^2 = \frac{1}{\sigma_R^2} \sum_{i=1,2,3} \left(\frac{x}{R_i} \right)^2$$

$$G_2 y^2 = \sum_{i=1,2,3} \frac{1}{\sigma_{y_i}^2} = \frac{1}{\sigma_R^2} \sum_{i=1,2,3} \left(\frac{\partial R_i}{\partial y} \right)^2 = \frac{1}{\sigma_R^2} \sum_{i=1,2,3} \left(\frac{y-y_i}{R_i} \right)^2$$

$$G_3 x\ y = \frac{1}{\sigma_R^2} \sum_{i=1,2,3} \left(\frac{\partial R_i}{\partial x} \right)\left(\frac{\partial R_i}{\partial y} \right) = \frac{1}{\sigma_R^2} \sum_{i=1,2,3} \left(\frac{x}{R_i} \right)\left(\frac{y-y_i}{R_i} \right)$$

where $y_{1,2,3} = (-a, 0, a)$

Computing the axis of the equal error ellipse:

$$\frac{1}{a^2}=\frac{1}{2}(G_1+G_2)+\sqrt{\left((G_1-G_2)^2+G_3^2\right)}$$
$$\frac{1}{b^2}=\frac{1}{2}(G_1+G_2)-\sqrt{\left((G_1-G_2)^2+G_3^2\right)}$$

Converting this axis to an axis that contains the probability of P (0<P<1), the a and b axis should be multiplied by:

$$\sqrt{-(2*\log\{1-P\})}$$
$$A=a*\sqrt{-(2*\log\{1-P\})}$$
$$B=b*\sqrt{-(2*\log\{1-P\})}$$

Thus, the total error is estimated as:

$$CEP\approx 0.75*\sqrt{A^2+B^2}$$

Alternate Embodiments and Applications of the Present Invention

Many embodiments of the present invention are envisioned and only a few will be detailed here. The one embodiment discussed at length above is the replacement for the computer mouse. An enhanced mouse embodiment would provide functionality beyond that capable of an ordinary mouse or trackball. For example, using a laptop or notepad computer is sometimes awkward to operate due to the fact that the built-in mouse or mouse replacement (such as joysticks or touchpads or pointer buttons) are not easy to use. This is especially true in situations where the mobile user uses the laptop computer in vehicles such as in trains, airplanes, cars, busses, etc. The present invention

provides a small and easy-to-use replacement of the mouse as an add-on or as a simple attachment that does not require additional space.

In a mouse replacement application of the present invention, the user simply approaches the location on the screen in which he wishes to place the cursor by using the stylus 101. The cursor will be "pulled" when the stylus is at a distance of less than approximately 2 cm from the screen. Approaching closer to a distance of approximately 1 cm will be the equivalent of a traditional mouse left hand-side pushbutton. As described above, left and right pushbuttons are an added option to the stylus.

One of the most significant applications of the virtual pen of the present invention is in the simplification of data entry and editing of computer graphics. Figure 4 shows an example of using the present invention on a laptop computer 400. In today's world, presentations and technical material use software programs such as Microsoft® PowerPoint® or Visio® programs for expressing ideas in a simple and apparent ways. The conventional mouse does not always provide the right and intuitive tool for these applications. The present invention provides the missing element for simple computer drawing. The user draws straight lines as simple as he or she does on paper using a conventional pen or pencil.

Figure 5 shows an implementation of the present invention for a drawing pad or touchpad 540 replacement. The existing electronic notepads (such as PalmPilot) are somewhat inconvenient to use for taking large amount of notes during lectures since the writing area is too small. Palmtop computers are expensive and their batteries could not maintain a whole day of school. The present invention, as a touchpad replacement 540 allows students or others to take notes in hand writing. After the lecture (or in real time) the data could be stored in the computer 501 and manipulated by pattern recognition software into alphanumeric standard files. The drawing tablet 540 of Figure 5 is shown connected to a desktop for downloading the stored handwriting. Tablet or pad 540 can also be connected to a laptop 400. In addition, the tablet 540 may be implemented with enough internal memory and processing power to hold a great deal of graphical information and may be carried into the lecture hall as a stand-alone device.

Further, the tablet 540 of Figure 5 may have a paper writing area and the stylus may be implemented with an ink reservoir and tip (as found in a conventional writing apparatus) such that the writing or graphics is done on paper and simultaneously recorded. Using special software such as Palm writing could allow a direct conversion of the handwriting into alphanumeric standard files stored on the tablet 540. Further, different colors could be used in the stylus either by several multicolor pens 101 or a pen stylus that contains several colors by color selection which would be sensed by the receiver 300 of the present invention. Also, the touchpad replacement 540 may utilize a wireless connection to computer 501 via infrared (IR) communication.

A writing pad implementation of the present invention is similar to the touchpad but the resolution would be much better. The writing pad could be an independent device with large memory that will store the hand-written information and download it later to the computer 501. In yet another embodiment, the virtual pen system is implemented as an engineering tool that will allow reading distances on maps with changeable scales, as well as allowing 2d (two dimensional) and 3D (three dimensional) measurements of small bodies and physical objects. The size of the sensed object is only limited by the placement and sensitivity of the microphones 102. It is conceivable to implement a very large virtual pen system.

Variations and Equivalents of the Present Invention

Many equivalent implementations of the described embodiments of the present invention are likely without departing from the central concept of the present invention. By way of example, but not by limitation, the carrier frequencies, the duty cycles, the number of encoded bits, the modulation technique and the direct sequence coding may all be varied in order to achieve an optimal implementation of the present invention. Ultrasound is broadly defined as frequencies above the human capability for detection. Bi-phase shift keying modulation is but one modulation technique of many alternate techniques such as phase shift keying, quadrature phase shift keying, frequency shift keying, Gaussian minimal shift keying, to name a few. Other types of frequency modulation, amplitude modulation, phase modulation, and combinations thereof may also be practical for use with the present invention.

Various circuit implementations are also contemplated for use in implementing the present invention. Although the preferred embodiments are described in the present description, these described embodiments are not to be viewed as limiting the claimed invention. For example, microprocessors 206 and 306 may be implemented as microcontrollers, digital signal processors, programmable logic arrays, and other types of controllers, which may be used to control the operations of the stylus 101 and the receiver circuit 300. The location algorithms may be implemented in hardware, software, or any combination of the two. Modulation circuits in the stylus 101 may be phase locked loop circuits, or many other variations. ASIC (application-specific integrated circuits) devices may combine a large number of analog and digital circuitry, such as most of the components of Figure 3, into a single package.

Conclusion

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiments shown. Many adaptations of the invention will be apparent to those of ordinary skill in the art. Accordingly, this application is intended to cover any adaptations or variations of the invention. It is manifestly intended that this invention be limited only by the following claims and equivalents thereof.

What is claimed is:

1. A virtual pen computer input system, comprising:

a stylus containing a first processor and a speaker for sending a modulated ultrasound signal;

a receiver circuit, having:

a plurality of microphones positioned around the periphery of a plane area to receive the modulated ultrasound signal;

a processor connected to the plurality of microphones and operable for computing the location of the stylus upon activation of the stylus by the user; and

a computer interface connected to the processor for sending the stylus location to a computer.

2. The system of claim 1 further including a calibration speaker mounted in proximity to the plurality of microphones and connected to the processor for measuring the speed of sound in real time and adjusting the stylus location accordingly.

3. The system of claim 1 wherein the stylus further includes a sensor for detecting whether the stylus is being held in a user's hand.

4. The system of claim 3 wherein the sensor includes a motion detector to sense motion of the stylus and an impedance detector to measure the impedance between to conductors when the stylus is gripped by a human hand.

5. The system of claim 1 wherein the plane area is selected from the list of a computer CRT display, a flat panel display, a writing tablet, a PDA screen and a drafting tablet.

6. The system of claim 1 wherein the modulated ultrasonic signal has a carrier frequency above the detection of a human ear.

7. The system of claim 6 wherein the modulated ultrasonic signal is modulated using a direct sequence of pseudo random digital data and where the sequence is selected to be unique to this system so that interference from other systems is minimized.

8. The system of claim 1 wherein the stylus location is resolved in three dimensions and the processor determines how close to the plane area the stylus is located in the z-axis above the plane area.

9. The system of claim 1 where the processor is also operable for performing a dynamic location Kalman filter to enhance the stylus location and avoid erroneous locations.

10. A stylus for use in a computer input system, comprising:

a pen-like body adaptable for holding by a user;

a gripping sensor;

an ultrasonic transducer; and

a processor connected to the gripping sensor and the ultrasonic transducer and contained within the body, the processor executing instructions for detecting the grip of the user and for transmitting ultrasonic coded information through the ultrasonic transducer.

11. The stylus of claim 10 further including a motion detector connected to the processor for sensing the motion of the stylus.

12. The stylus of claim 10 further including a switch connected to the processor and wherein the closing of the switch causes the processor to indicate the closure in the coded information.

13. The stylus of claim 12 wherein the switch is a mouse button and the closure of the switch indication a selection of a current location of the stylus.

14. The stylus of claim 10 wherein the switch is a color selection button and the closure of the switch indication a selection of a color.

15 The stylus of claim 10 wherein the gripping sensor detects a change of impedance between two conductors when user grips the pen-like body.

16. The stylus of claim 10 further including a cradle adapted to receive the pen-like body and operable when connected to the stylus for charging a battery within the stylus.

17. The stylus of claim 10 further including a cradle adapted to receive the pen-like body and operable when connected to the stylus for synchronizing the coded information.

18. A receiver apparatus for computer information input, comprising:

a plurality of microphones positioned at unique positions around the periphery of an area to receive a coded ultrasound signal transmitted from a source location;

a processor connected to the plurality of microphones and operable for detecting the coded modulated ultrasound signal at each of the plurality of microphones, for decoding the coded ultrasound signal to isolate only the ultrasound signals of interest, for measuring time delay differences of the coded ultrasound signal received at each microphone, and for comparing the time delay differences and calculating a numerical value for the source location; and

a computer interface connected to the processor for sending the numerical value to a computer.

19. The receiver apparatus of claim 18 further including a calibration speaker located in proximity to the area and connected to the processor for measuring the speed of sound.

20. The receiver apparatus of claim 18 wherein the numerical value represents a three dimensional location within the area.

21. The receiver apparatus of claim 18 wherein the numerical value represents a location within the area and the speed of the movement of the source location.

22. A method of inputting position information into a computer, comprising:

producing ultrasonic coded signals at a selected location within a defined area;

detecting the ultrasonic coded signals at a plurality of locations around the periphery of the defined area;

decoding the ultrasonic coded signals to isolate only the ultrasonic signals produced at the selected location;

measuring the time of arrival difference of the ultrasonic coded signals at each of the plurality of locations; and

comparing the time of arrival differences and calculating a numerical value of the selected location.

23. The method of claim 22 wherein the numerical value represents a three dimensional location within the defined area.

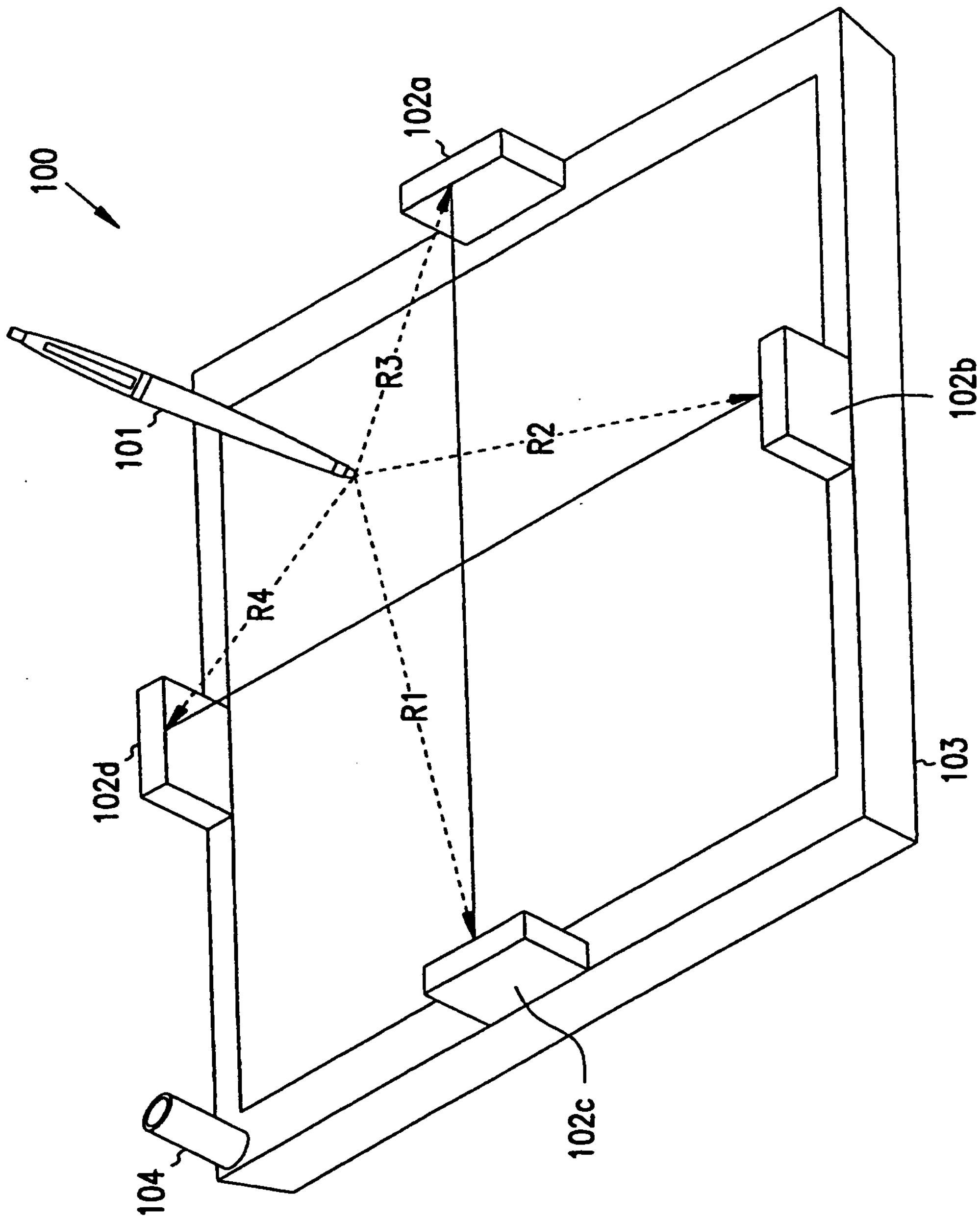


Figure 1

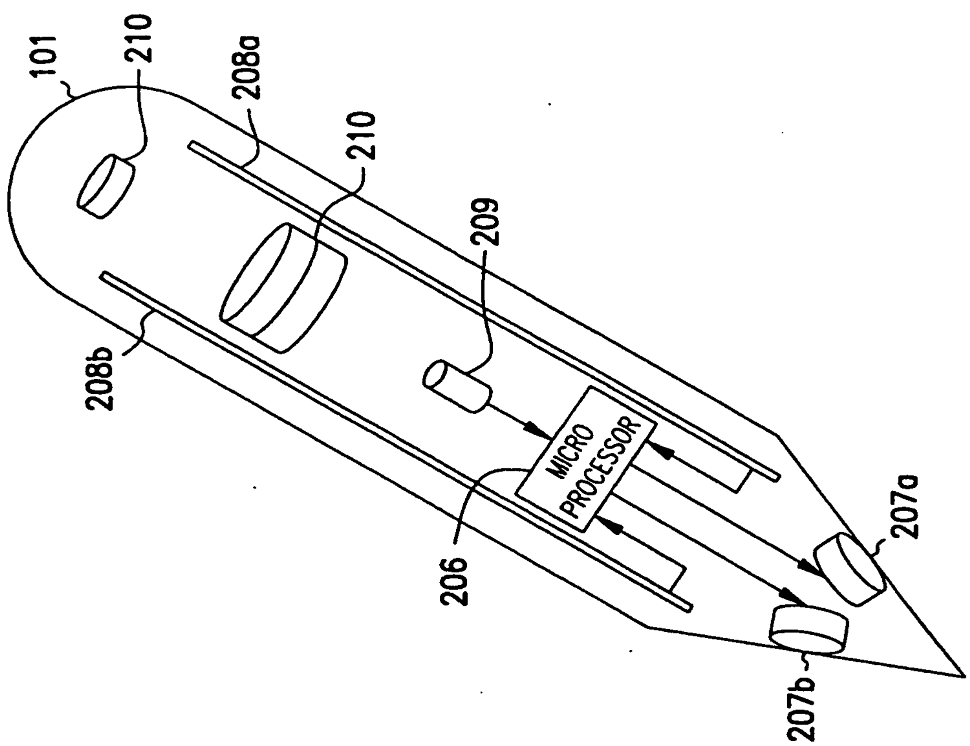
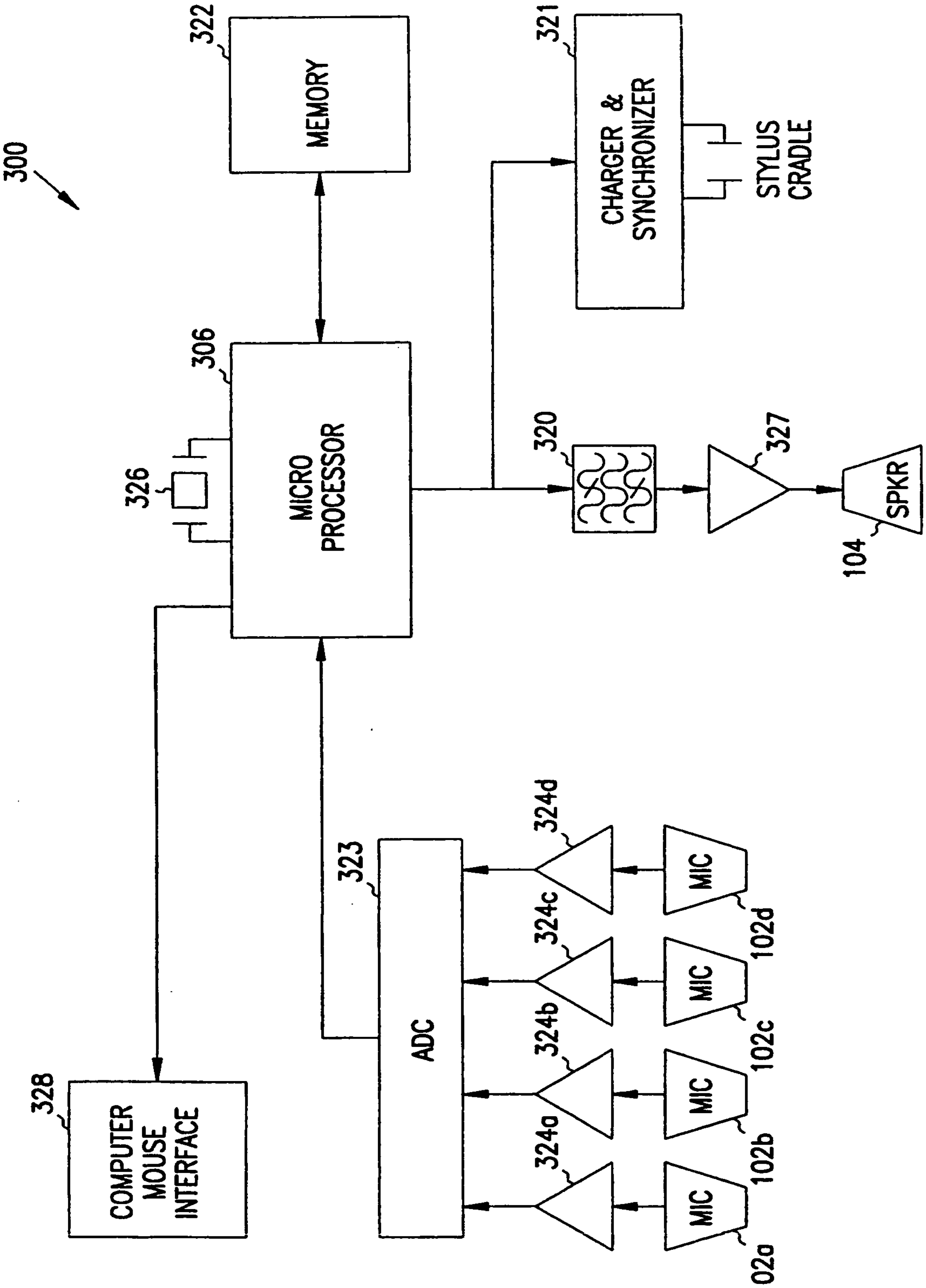


Figure 2


300
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MEMORY
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CHARGER & SYNCHRONIZER
STYLUS CRADLE
306
MICRO PROCESSOR
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SPKR
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COMPUTER MOUSE INTERFACE
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Figure 3

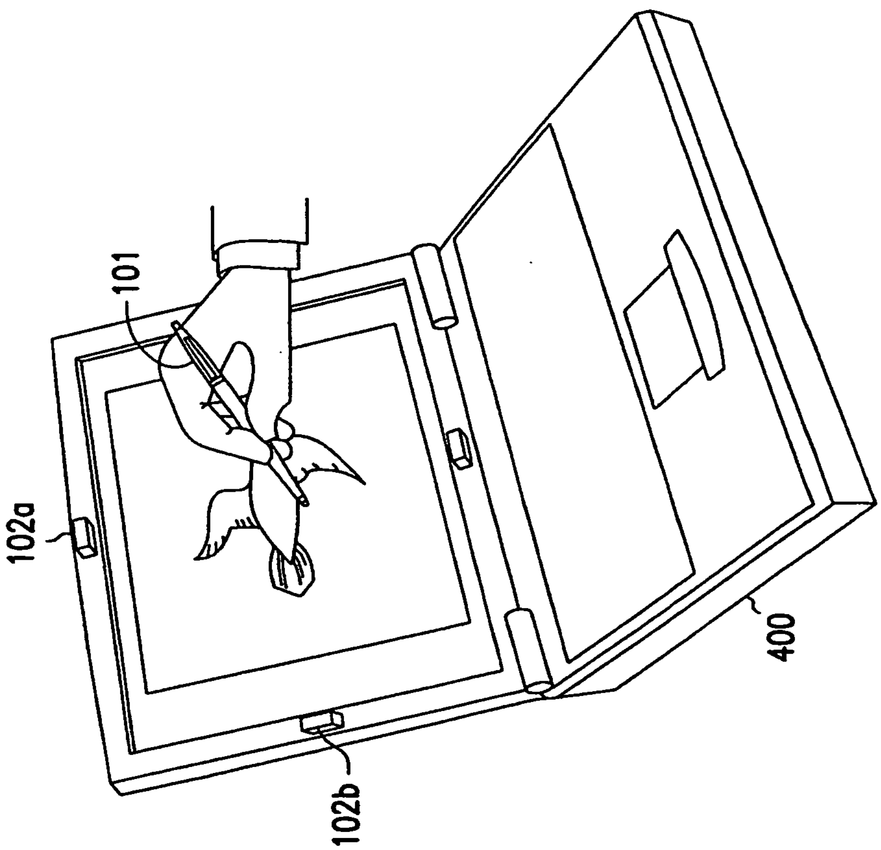

Figure 4

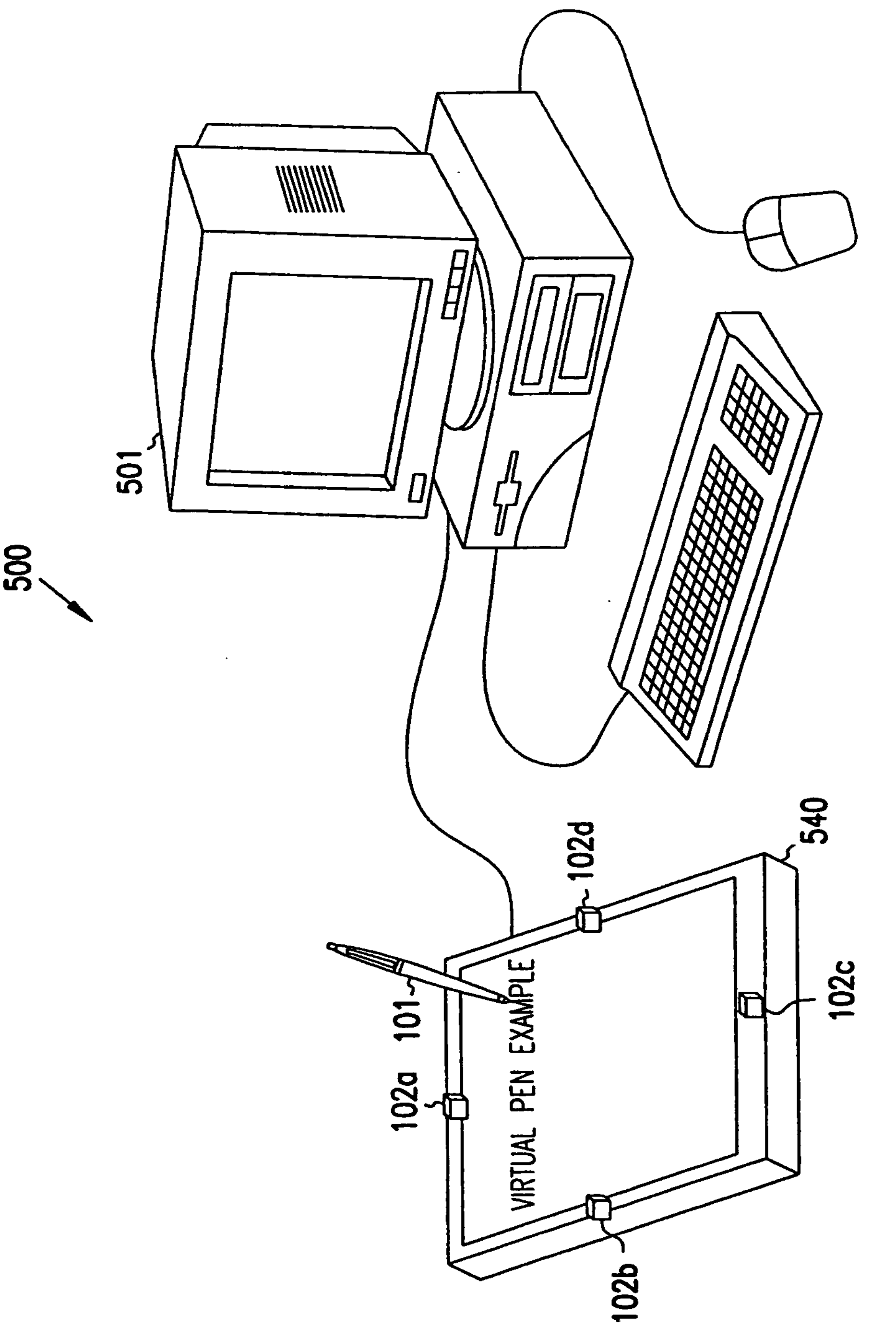

Figure 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 00/00234

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06K11/14 G06K11/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 717 168 A (DEBUISSER THOMAS ET AL) 10 February 1998 (1998-02-10)	1-5, 10-14, 16,18, 19,21,22
	column 5, line 37 -column 9, line 7; figures 1-3,6 column 13, line 13 - line 18	
Y		8

X	US 4 814 552 A (STEFIK MARK J ET AL) 21 March 1989 (1989-03-21) cited in the application column 2, line 30 - line 68; figure 1 column 3, line 22 - line 57	1,5,6, 18,21,22

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
7 August 2000	14/08/2000

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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